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Berry Brook Watershed Management Plan –Implementation Projects Phase III

The City of Dover

University of New Hampshire Stormwater Center (UNHSC)

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Final Report to
The New Hampshire Department of Environmental Services
Submitted by

The City of Dover and the UNH Stormwater Center
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Executive Summary

Berry Brook is a highly urbanized 1st order stream located in Dover, NH, that is classified as Class B waters. The Brook is located in a built-out, 186-acre watershed with 29.7% effective impervious cover (EIC) and includes medium-density housing with commercial and industrial uses. The stream has been placed on the NHDES 2006 Section 303(d) list and is impaired for primary recreation and for aquatic life. The source of this impairment includes urbanization resulting in an increase of pollutant mass and runoff volumes from stormwater.

With funds provided by the New Hampshire Department of Environmental Services (NHDES) the City of Dover has been working with the University of New Hampshire Stormwater Center (UNHSC) and the Cocheco River Watershed Coalition to design and implement Low Impact Development (LID) best management practices (BMPs) in this highly urbanized environment for the purpose of effective impervious cover (EIC) reduction.

The project goal is to filter, infiltrate, and reduce stormwater runoff from EIC as a means for managing pollutant loading and controlling runoff volumes to Berry Brook and consequently the Cocheco River. This project is the third and final phase of an overall watershed management plan implementation project. Previously in phases I and II, a total of twelve stormwater BMP installations were implemented leading to a reduction in 27 acres of effective impervious cover (EIC) and a total effective impervious cover (EIC) for the watershed of 29 acres down from 56 acres at the start of the project. For the purposes of this project EIC refers to impervious cover (IC) that is directly connected, through impervious surfaces, to receiving waters. Disconnection refers to the practice of directing runoff from IC such that it does not contribute directly to stormwater runoff from a site, but directs stormwater runoff to an appropriately sized, on-site treatment practice, or vegetated buffer to be filtered or infiltrated into the native soils. By the end of Phases I and II of the project the EIC% in the watershed was 16% down from 30% at the start of the project.

A total of eight more BMPs were implemented in Phase III as well as a rain barrel program, which was a (non-structural) homeowner-scale stormwater BMP implementation. The eight additional structural BMPs of phase III included two bioretention systems, two innovative subsurface gravel filters, an infiltration trench, and three innovative filtering catch basins. It should be noted that as the list of BMPs implemented in the project grew, new systems had to be invented in order to effectively disconnect EIC and still meet the maintenance standards of the City. This re-invention process is one of the most unique and impactful developments of this project. This partnership between NHDES, UNHSC and the City has reduced the cost, increased the effectiveness, and led to more maintainable systems. Combined, these installations led to the disconnection of an additional 9.6 acres of EIC. By the end of Phases I, II, and III of the project the EIC% in the watershed is now 10.4%, meeting the final project goal of getting to 10% EIC. In total these efforts are aimed at bringing the impaired water back to the level of achieving regulatory criteria and overall reduce pollutant loading of suspended sediment, phosphorous and nitrogen (total) by 17,514, 68 and 354 pounds per year, respectively.

Introduction

Berry Brook, a tributary to the Cocheco River, is a 0.9 mile long stream in a 186-acre watershed in downtown Dover that is nearly completely built-out with 30% effective impervious cover (EIC) at the onset of the project. The brook is listed as impaired for aquatic habitat and primary contact recreation. This project is the third and final phase of a series of grants implementing restoration actives recommended in the Berry Brook Watershed Management Plan (WMP) completed in 2008 (LBG, 2008).

The City of Dover was assisted in this Grant by the University of New Hampshire Stormwater Center (UNHSC) and New Hampshire Department of Environmental Services (NHDES). The UNHSC: provided recommendations on low impact development (LID), survey work, retrofit designs, and engineering oversight of the stormwater treatment systems; coordinated community outreach activities in conjunction with NHDES and the city; and developed post construction reports and modeling. In addition a modest monitoring effort was undertaken and coordinated by the City of Dover and the UNHSC to track receiving water impacts pre- and post- project completion. The City of Dover, from the Department of Public Works (DPW) and administration of the overall grant, generously provided matching funds over the entire scope and timeframe of the project in the form of time, equipment, and materials in the construction of BMPs. All treatment practices were designed by the UNHSC in close collaboration with the City and installed by the DPW, with engineering oversight provided by UNHSC.

This project builds upon the previous two phases of activities documented in the original WMP which was adapted through phased proposals to NHDES. This project addresses water quality impairments associated with stormwater runoff from a highly urbanized area. Specifically, uncontrolled runoff from medium density residential and commercial properties is directly addressed through a combination of filtration and infiltration measures. Concurrent with this project, another proposal was received from the NHDES Aquatic Resource Mitigation (ARM) program to fund stream and wetland restoration efforts at the headwaters and tail waters of the brook. The overall project goal was to disconnect EIC by intercepting, filtering, infiltrating, and reducing stormwater runoff from untreated IC as a means for managing pollutant load and controlling runoff volumes to Berry Brook and consequently the Cocheco River. The target EIC percentage of 10% (which was based on the impervious cover model assessment method NHDES uses to determine attainment) was met. These series of projects (3 watershed assistance grants and 1 aquatic resource mitigation grant) and the ensuing partnership have resulted in the installation of 26 low impact development (LID) and green infrastructure (GI) retrofits. Installations include: 12 bioretention systems, a tree filter, a subsurface gravel wetland, one acre of new wetland, day lighted and restored 1,100 linear feet of stream at the headwaters and restored 500 linear feet of stream at the confluence including two new geomorphically-designed stream crossings, three grass-lined swales, two subsurface gravel filters, an infiltration trench system and developed an innovative filtering catch basin design that has been installed in 3 different locations in the watershed. Some of the stormwater BMPs were based on designs tested at the UNHSC field site and proven for their ability to treat water quality and reduce runoff, and other systems were re-invented by City staff to decrease costs and reduce operation and maintenance burdens. The ability for City staff to reinvent and adapt stormwater BMPs was critical to the success of the project and involved the direct participation of respected staff like Bill Boulanger, Superintendent of Public Works and Utilities for the city and Gretchen Young, the assistant City Engineer. They were able to tackle three fundamental challenges that are often associated with municipal adoption of innovative stormwater management approaches: compatibility, complexity and trialability, or in other words, does it fit the management culture, can people understand it, and can local staff adapt the designs for greater utility? Due to the inherent flexibility of innovative LID management strategies, it seems logical that trusted municipal officials experiment with designs to more easily adapt seemingly complex configurations into a form more readily understood and accepted by peers.

The Impervious Cover Model (ICM) was first proposed in 1994 by Tom Schueler and the Center for Watershed Protection. It was first introduced as a management tool to diagnose the severity of future stream problems in urban and urbanizing watersheds. Since its introduction the ICM has been adapted as a surrogate for impaired water attainment. Numerous watershed studies throughout the country have correlated the percentage of IC to the overall health of a watershed and its ability to meet designated uses. National studies have also demonstrated that stream quality indicators will decrease as the percent of IC increases (Schueler 1994; Schueler et al. 2009). More local studies have verified this threshold as well (Deacon et al. 2005).

Stream studies performed by the Center for Watershed Protection support the use of IC as a surrogate measure of the impacts on hydrology, chemistry, and biology of a stream, including impacts to aquatic life. There is also a strong correlation between pollutant loads and stormwater flows from impervious areas. According to studies, it is reasonable to rely on the surrogate measure of percent IC to represent the combination of pollutants that can contribute to aquatic life impacts (Schueler et al. 2009). The ICM concept has engendered much debate and some confusion among planners, engineers, and regulators. Most communities continue to struggle with how to influence or optimize watershed IC limits and/or how to apply techniques to mitigate its impact.

PROJECT PERFORMANCE: OBJECTIVES AND DELIVERABLES

The objectives and deliverables of this final report are outlined below.

Objective 1: **Implementation of Low Impact Development (LID)** Best Management Practices (BMPs) to disconnect impervious cover (IC) and reduce pollutant loading at eight locations throughout the Berry Brook watershed will be completed. The completion of this objective will represent 83% completion of the BMPs recommended in the Watershed Management Plan (LBG, 2008), and will lead to the reduction of Effective Impervious Cover (EIC) in the entire watershed to 10.4% fulfilling the criteria to delist the Berry Brook from the 303d impaired waters list based on the impervious cover model as a surrogate for attainment.

Measures of Success: Installation of each of the LID BMP retrofits.

Summary of Objective 1 Activities

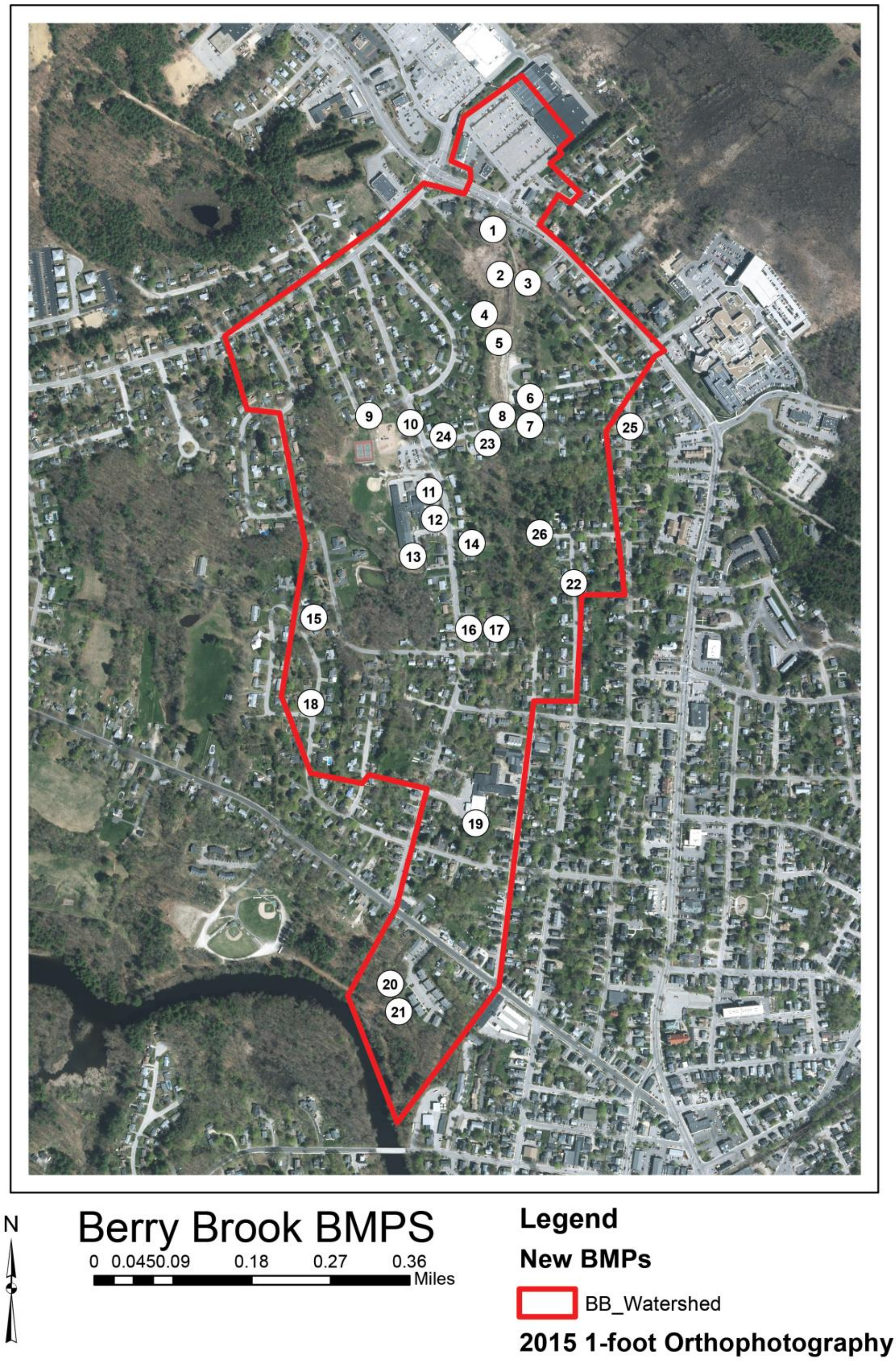

FIGURE 1: GREEN INFRASTRUCTURE RETROFITS IN THE WATERSHED THROUGHOUT THE PROJECT PERIOD.

Stormwater treatment practices were installed at various locations throughout the Berry Brook watershed to infiltrate and treat stormwater runoff from building rooftops and parking areas.

Photograph 1: Bioretention system at Roosevelt Avenue

Deliverable 1: Roosevelt Avenue Bioretention. A series of catch basins and treatment systems were installed off of Roosevelt Avenue to treat a drainage area of 1.9 acres with 0.92 acres of previously untreated DCIA associated with suburban residential development. Runoff from existing roadway was collected by a series of two deep sump catch basins (CB #3 and #4) and directed to a stone infiltration basin off the north side of Roosevelt Avenue. The infiltration basin was designed to remove coarse sediments and debris while also reducing the velocity of the runoff before discharging to a deep sump catch basin (CB #2). Discharge from CB #2 was directed to a bioretention system designed to treat a water quality volume of 0.15 inches. The bioretention system discharges to an additional deep sump catch basin (CB #1) before discharging to Berry Brook. In addition a stone infiltration trench was installed to manage and treat sheet flow across an un-stabilized area between the old waterworks building and Berry Brook. The infiltration trench also serves as part of a pedestrian path leading through the upper Berry Brook restoration area. The Roosevelt installation was constructed in May through June of 2014. Details of the installation are provided in the photo documentation and design drawing in Appendix A.

Photograph 2: Bioretention system at lower Horne Street

Deliverable 2: Horne Street Bioretention 2

A bioretention system was designed and installed to treat runoff from 4.78 acres of drainage area with 1.88 acres of previously untreated DCIA associated within a suburban residential development. Discharge from existing roadside runoff was directed to a series of deep sump pre-treatment catch basins on either side of the road and then piped to the bioretention system. System was constructed in October of 2013. Details of the installation are provided in the photo documentation and design drawing in Appendix A.

Photograph 3: Roosevelt Avenue filtering catch basin 1.

Deliverable 3: Roosevelt Filtering Catch Basin 1

The close partnership between UNHSC staff and city DPW employees has resulted in new and innovative adaptations to conventional GI designs that resulted in more effective, more economical, and easier to maintain system designs. The City of Dover worked directly with UNHSC staff to ensure that the systems being implemented could not only be maintained with existing personnel and equipment but could be affordable and understood by local staff. This system was the first iteration of a deep sump catch basin that also filters first flush stormwater runoff. The system was designed and installed to treat runoff from 1.4 acres of drainage area with 0.59 acres of previously untreated DCIA associated with a suburban residential development. Details of the installation are provided in the photo documentation and design drawing in Appendix A.

Photograph 4: Grove Street subsurface gravel filter.

Deliverable 4: Grove Street Subsurface Gravel Filter

Another innovation pioneered in this project was the development of a subsurface gravel filter. Lacking equipment to maintain the recommended porous asphalt system, they developed the "Boulanginator," a system that mimics the features of a porous asphalt system through a subsurface storage and filtration component connected to easily maintainable catch basins. This system looks like a typical cross-section of a porous pavement but is paved with normal dense mix asphalt. The hydraulic inlet and outlet are instead controlled through perforated inlets and underdrains. The system was designed and installed to treat runoff from 1.96 acres of drainage area and 0.61 acres of previously untreated DCIA associated with a suburban residential development. Details of the installation are provided in the photo documentation and design drawing in Appendix A.

Photograph 5: Hillcrest Avenue infiltration trench.

Deliverable 5: Hillcrest Avenue Infiltration Trench

Taking advantage of highly permeable soils (HSG A) City staff installed additional drainage structures and instead of connecting them with solid pipe, connected them with perforated pipe bedded in two feet of crushed stone. A simple but effective adaptation, this approach can be replicated in other suitable areas throughout the city. The system was designed and installed to treat runoff from 3.36 acres of drainage area and 1.04 acres of previously untreated DCIA associated with a suburban residential development. Details of the installation are provided in the photo documentation and design drawing in Appendix A.

Photograph 6: Roosevelt Avenue filtering catch basin 2.

Deliverable 6: Roosevelt Filtering Catch Basin 2

The close partnership between UNHSC staff and city DPW employees has resulted in new and innovative adaptations to conventional GI designs that resulted in more effective, more economical, and easier to maintain system designs. The City of Dover worked directly with UNHSC staff to ensure that the systems being implemented could not only be maintained with existing personnel and equipment but could be affordable and understood by local staff and personnel. This system was the second iteration of a deep sump catch basin that also filters first flush stormwater runoff. The system was designed and installed to treat runoff from 2.02 acres of drainage area and 0.77 acres of previously untreated DCIA associated with a suburban residential development. Details of the installation are provided in the photo documentation and design drawing in Appendix A.

Photograph 7: Kettlebell Subsurface Gravel Filter

Deliverable 7: Kettlebell Subsurface Gravel Filter

The first of the subsurface gravel filter systems installed is located in the parking lot of Seacoast Kettlebell, a fitness center located off of Horne Street. The primary treatment mechanism of this control is filtration; however, the design may also reduce runoff volumes through infiltration. Due to the extremely low hydraulic conductivity of the native soils at this site, volume reduction through infiltration is most likely negligible. The system was designed and installed to treat runoff from 2.41 acres of drainage area and 1.73 acres of previously untreated DCIA associated with a suburban residential development. Details of the installation are provided in the photo documentation and design drawing in Appendix A.

Photograph 8: Grove Street filtering catch basin.

Deliverable 8: Grove Street Filtering Catch Basin 1

The close partnership between UNHSC staff and city DPW employees has resulted in new and innovative adaptations to conventional GI designs that resulted in more effective, more economical, and easier to maintain system designs. The City of Dover worked directly with UNHSC staff to ensure that the systems being implemented could not only be maintained with existing personnel and equipment but could be affordable and understood by local staff and personnel. This system was the third and final iteration of a deep sump catch basin that also filters first flush stormwater runoff. The City has purchased four additional filtering catch basins and will install them in other areas throughout the city. The system was designed and installed to treat runoff from 0.68 acres drainage area and 0.32 acres of previously untreated DCIA associated with a suburban residential development. Details of the installation are provided in the photo documentation and design drawing in Appendix A.

Objective 2: A site specific project plan (SSPP) for tracking pre- and post-project IC values and pollutant load reductions will be developed.

Measures of Success: SSPP developed and approved.

The SSPP was developed and approved. It is on file with NHDES.

Objective 3: Calculate Pollutant Load Reductions and Disconnected Impervious Cover

Measures of Success: Hydrological and water quality data, pre- and post-IC estimates developed, project impact evaluated.

As outlined in the Site Specific Project Plan, UNHSC used the Simple Method to estimate load reduction for this project. The Simple Method is recommended by NHDES for use on Section 319 grant projects. The model was used to estimate pre- and post-BMP implementation pollutant loads. We note that the Simple Method does not account for volume or flow reductions and therefore may underestimate the pollutant load reductions achieved by each BMP. As such, UNHSC has refined the model using a technical support document produced specifically for NH by EPA Region 1 (EPA, 2011). The method can be used to determine DCIA reduction based on Interim Default BMP Disconnection Multipliers. The subsequent runoff reduction can then be subtracted from the pollutant load as it has been hydraulically disconnected from conveyance to the receiving water. This method was not available and thus not included in the SSPP report however it follows standards and quality assurance criteria outlined by EPA Region 1 and offers a better estimate of actual load reduction.

Below is a summary of the disconnected impervious area (IA) and the pollutant load reduction for each BMP.

Deliverable 10

The table below depicts the eight structural and one non-structural BMPs implemented through phase III of the project.

TABLE 1: IMPERVIOUS COVER DISCONNECTED IN PHASE III OF THE PROJECT

System	DA (acres)	DCIA (acres)	%IC
2013 Installs	**186**	**29**	**15.8%**
Horne Street 2	4.78	1.88	39%
2013 Total	**4.78**	**1.88**	**1.0%**
2014 Installs	**186**	**28**	**14.8%**
Roosevelt Street	1.90	0.92	48%
2014 Total	**1.90**	**0.92**	**0.5%**
2015 Installs	**186**	**26.6**	**14.3%**
Kettle Bell	2.41	1.73	72%
Grove Street	1.96	0.61	31%
Hillcrest Avenue	3.36	1.04	31%
2015 Total	**186**	**3.4**	**1.8%**
2016 Installs	**186**	**23.2**	**12.5%**
Roosevelt FCB 1	1.40	0.59	42%
Roosevelt FCB 2	2.02	0.77	38%
2016 Totals	**186**	**1.4**	**2.1%**
2017 Installs	**186**	**21.9**	**11.7%**
Rain barrel Program	2.15	2.15	100%
Grove Street FCB 1	0.68	0.32	48%
2017 Totals	**186**	**19.4**	**2.1%**
BB WAG III Watershed Totals	**186**	**19.4**	**10.4%**

Table 2 depicts the eight structural and one non-structural BMPs implemented through all phases (I – III) of the project. Note, some of the BMPs implemented in phase I of the project were funded through NHDES Aquatic Resource Mitigation funds.

TABLE 2: IMPERVIOUS COVER DISCONNECTED IN ALL PHASES OF THE PROJECT

	DA	IC or DCIA	IC
	AC	AC	%
2011 Installs	**186**	**56**	**30%**
Central Avenue - Gravel Wetland	12.10	10.50	86.8%
Wetland (Weir Wall)	14.81	2.24	15.1%
14-16 Crescent Street	3.27	1.47	45.1%
HSS Bio 1	0.16	0.16	100.0%
HSS Bio 2	0.12	0.08	64.4%
Snow Avenue	4.57	1.72	37.6%
Page Avenue	5.75	2.07	36.0%
15A Hillcrest Drive	0.03	0.03	93.8%
HSS Tree Filter	0.29	0.29	100.0%
2011 Total	**41**	**19**	**10.0%**
2012 Installs	**186**	**37**	**20.0%**
12 Lowell Avenue (WTP)	2.85	1.21	43%
Glencrest Avenue	7.49	2.49	33%
Upper Horne Street	13.44	4.11	31%
2012 Total	**23.78**	**7.81**	**4.2%**
2013 Installs	**186**	**29**	**15.8%**
Horne Street 2	4.78	1.88	39%
2013 Total	**4.78**	**1.88**	**1.0%**
2014 Installs	**186**	**28**	**14.8%**
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2017 Installs	**186**	**21.9**	**11.7%**
Rainbarrel Program	2.15	2.15	100%
Grove Street FCB 1	0.68	0.32	48%
2017 Totals	**186**	**19.4**	**2.1%**
BB WAG I & II & III Watershed Totals	**186**	**19.4**	**10.4%**

Table 3 summarizes the pollutant load reduction estimates for phase III of the project.

TABLE 3: POLLUTANT LOAD REDUCTION ESTIMATES FOR PHASE III INSTALLATIONS

2013/2014 BMPs	Annual Load 'L_i' #/year	Effluent Load 'L_e" #/year	Annual PL Removed #/year
TSS #/year	7420.4	241.2	7179.2
TP #/year	29.7	3.3	26.3
TN #/year	163.2	16.3	146.9
2015 BMPs	Annual Load 'L_i' #/year	Effluent Load 'L_e" #/year	Annual PL Removed #/year
TSS #/year	4183.9	136.0	4047.9
TP #/year	19.6	2.2	17.4
TN #/year	107.9	27.0	80.9
2016 BMPs	Annual Load 'L_i' #/year	Effluent Load 'L_e" #/year	Annual PL Removed #/year
TSS #/year	2323.6	75.5	2248.1
TP #/year	9.3	1.5	7.8
TN #/year	51.1	12.8	38.3
2017 BMPs	Annual Load 'L_i' #/year	Effluent Load 'L_e" #/year	Annual PL Removed #/year
TSS #/year	4721.6	683.1	4038.5
TP #/year	18.9	2.8	16.0
TN #/year	103.9	16.1	87.8
Project Totals			
TSS #/year		**17,514**	
TP #/year		**68**	
TN #/year		**354**	

Table 4 summarizes the pollutant load reduction estimates for all phases (I, II and III) of the project.

TABLE 4: POLLUTANT LOAD REDUCTION ESTIMATES FOR PHASE ALL INSTALLATIONS

2011 BMPs	Annual Load 'L_i' #/year	Effluent Load 'L_e" #/year	Annual PL Removed #/year
TSS #/year	16757.6	1317.0	28465.7
TP #/year	65.4	13.4	98.1
TN #/year	409.7	71.3	634.2
2012 BMPs	Annual Load 'L_i' #/year	Effluent Load 'L_e" #/year	Annual PL Removed #/year
TSS #/year	7531.9	244.8	11243.6
TP #/year	27.1	4.4	35.3
TN #/year	115.9	29.0	139.0
2013/2014 BMPs	Annual Load 'L_i' #/year	Effluent Load 'L_e" #/year	Annual PL Removed #/year
TSS #/year	7420.4	241.2	7179.2
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TSS #/year	4721.6	683.1	4038.5
TP #/year	18.9	2.8	16.0
TN #/year	103.9	16.1	87.8
Project Totals			
TSS #/year		**57,223**	
TP #/year		**201**	
TN #/year		**1127**	

A summary of IC and pollutant load reductions may be found in Table 5.

TABLE 5: SUMMARY OF IC AND PLR REDUCTIONS THROUGHOUT THE PROJECT

Phase	Number of Installations	IC Disconnected	TSS #/year	TP #/year	TN #/year
III	9	10.0	17514	68	354
I-III	21	36.4	57223	201	1127

Objective 4: Project Monitoring

Summary of Objective 4 Activities

Deliverable 11

Hydrology

Urbanization and impervious surfaces typically reduce infiltration and alter the delivery of stormwater runoff to receiving waters. Urbanized areas modify natural drainage flow pathways and convey stormwater more quickly to receiving waters with far less water quality improvement than natural surfaces and flow paths. These urban stormwater conveyance systems tend to therefore increase peak flows which may then result in streambank erosion and alteration to stream geomorphology. Due to altered urban hydrology it becomes increasingly difficult to maintain stream habitat integrity. Furthermore, connected impervious cover has been found to decrease base (Hlas, 2012, Schueler 2009), flows in areas of moderately to heavily urbanized watersheds and increase temperatures in receiving waters further degrading aquatic habitat.

To measure the hydrologic project impacts, Aqua Troll 200 probes (manufactured by In-Situ Inc.) were used to monitor in stream water depths. Data was recorded every 15 minutes during the pre-LID, mid-LID and post-LID project periods. Stream gaging using the transect method was then performed at various stream stages at both the Roosevelt and Station locations. Stream gaging velocities were measured with a Marsh McBirney Current Meter. Mean velocities were measured by the six-tenths-depth-method and discharge was computed using the midsection method (USBR, 1975). From the stream gaging events, a stage-discharge calibration curve was developed (Figure 6) from which the real-time measured water depths could then be converted to real-time streamflow. Due to variable stream channel geometries at different depths, the rating curves do not obey a simple curve.

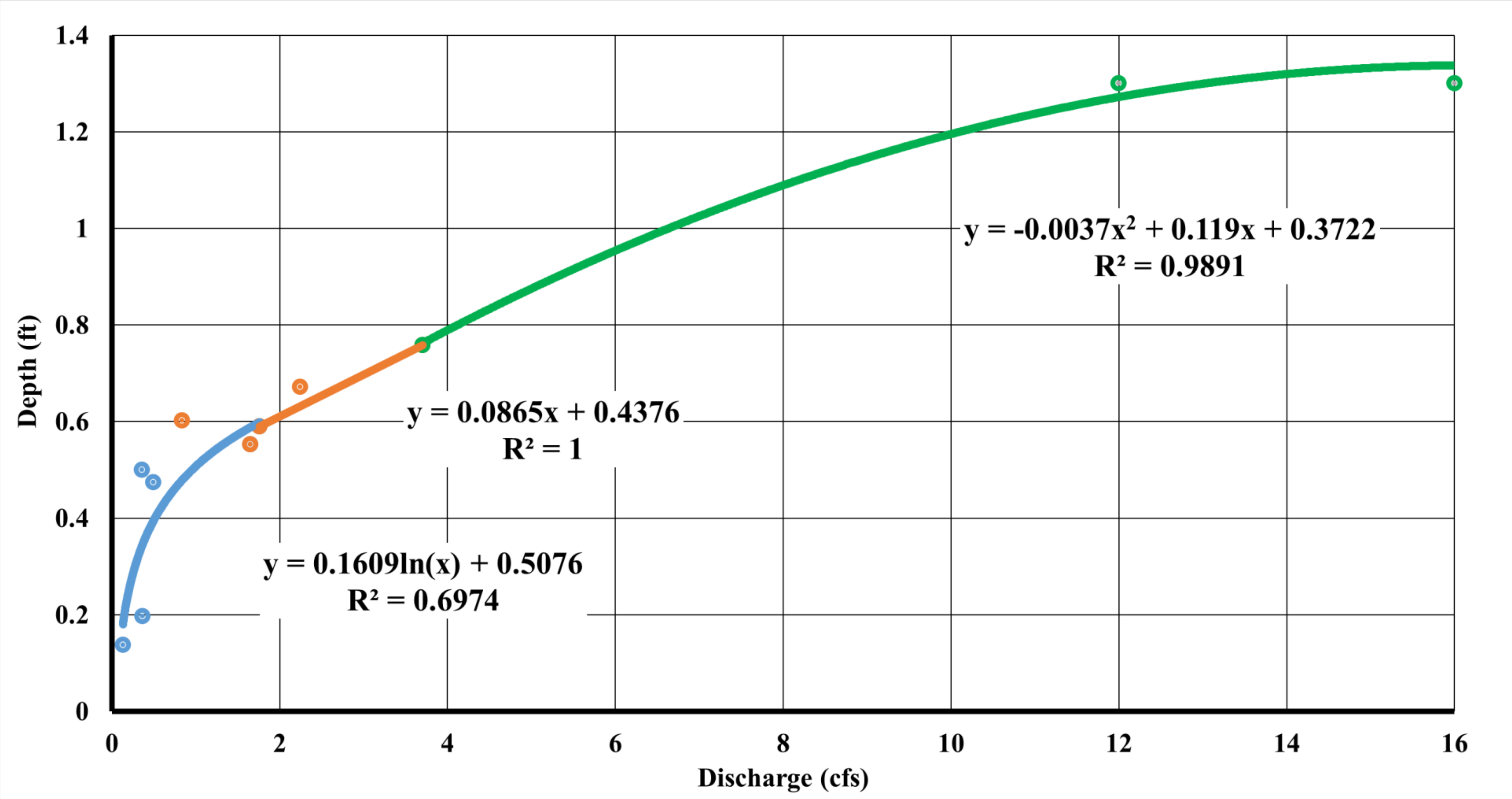

FIGURE 2: STAGE (DEPTH) DISCHARGE RATING CURVE FOR FLOWS IN THE BERRY BROOK AT THE DOWNSTREAM (STATION) MONITORING LOCATION.

The observed Berry Brook hydrology data was also analyzed on a storm event basis for the pre-LID (July-December 2011), mid-LID (January 2012 - August 2016), and post-LID (September - December 2016) time periods. Berry Brook storm event hydrograph parameters were then compared between these time periods. Direct runoff hydrographs were calculated using a constant slope base flow separation from the total runoff hydrographs for each storm event. The area under the direct surface runoff hydrographs is the volume of runoff. The volume of runoff divided by the watershed area is the runoff depth (effective precipitation). Implementation of green infrastructure should demonstrate that less runoff (effective precipitation) occurs for the same precipitation depth.

The trend lines of direct runoff vs. rainfall depths throughout the three distinct periods of the project demonstrate that the EIC of the drainage area is altering conventional runoff pathways as IC is disconnected throughout the project period. As project implementation trends toward 10% EIC the direct runoff decreases from the same relative precipitation depth. This illustrates that the enhanced BMPs implemented throughout the Berry Brook watershed are potentially mitigating or reversing the trend that increasing impervious areas imparts in the watershed.

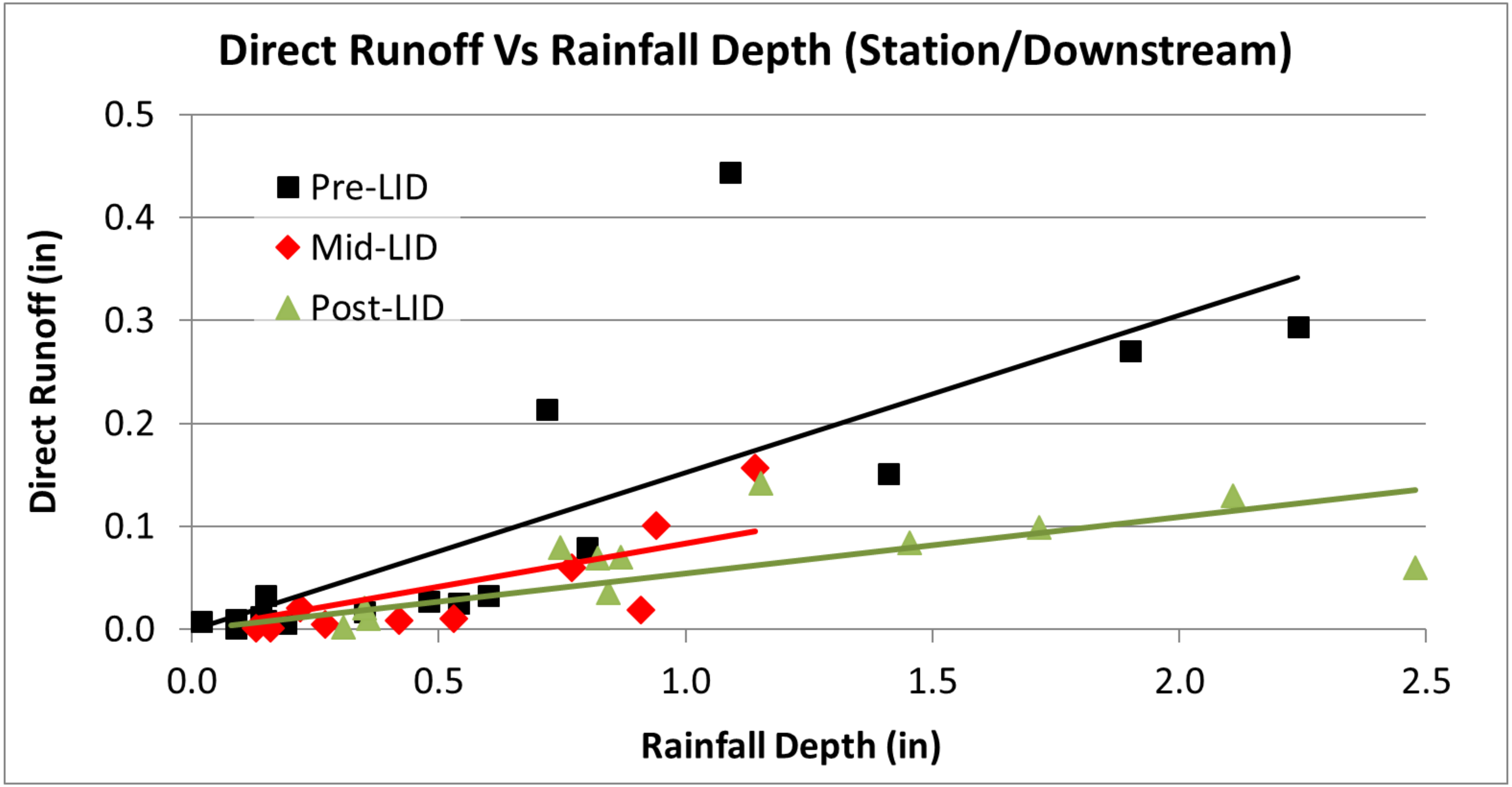

FIGURE 3: EMPIRICALLY DERIVED TRENDLINES OF DIRECT RUNOFF VS. RAINFALL DEPTHS FOR BERRY BROOK AT STATION DRIVE (DOWNSTREAM END) BETWEEN PROJECT PERIODS.

According to the impervious cover model, as BMPs are implemented throughout the watershed the hydrological regime should trend toward lower thresholds of excess precipitation. In conventional models this is demonstrated by a declining curve number (CN).

The Curve Number method was used to assess the effect of the GI implementation in Berry Brook. In this case, from Figure 6, at a precipitation depth of one inch (P), the direct runoff (Q) was read for each watershed EIC condition. Then for each pair of P-Q values, the potential maximum soil storage (S) was computed assuming initial abstraction as 5% of S (Lim, et al, 2006). From S, the Curve Number (CN) were developed (USDA, 2004). A high CN means much of the rainfall that fell from the sky runs off. As shown in Tables 6-7, it is evident that the Berry Brook watershed demonstrated dramatic reductions in runoff as GI was implemented.

TABLE 6: RESULTS FOR BERRY BROOK AT STATION DRIVE 1-INCH STORM, IA = 0.05 S

Year	% IC	P (in)	Q (in)	S (in)	CN	Q Reduction
2011	30	1.00	0.153	3.59	74	
2012	20	1.00	0.084	5.54	64	45.3%
2015	14	1.00	0.055	7.02	59	64.0%

Table 7 presents excess runoff and annual pollutant export mass in lbs. /year for different years throughout the project period. Naturally, as EIC is reduced excess runoff is reduced as shallow and deep groundwater pathways are reestablished, thereby affording additional evapotranspirative use of rainfall recharge. This is reflected in the curve number (USDA, 1986) which predicts excess runoff based on land use characteristics. Table 7 illustrates that although precipitation depths vary over the years of the study resultant runoff and subsequent pollutant loading to the stream are controlled due to the increase in abstraction in the managed urban environment.

TABLE 7: EXCESS RUNOFF AND ANNUAL POLLUTANT EXPORT BASED ON CHANGING LAND USE CONDITIONS (CN) AND ANNUAL PRECIPITATION DEPTHS (P) THROUGHOUT THE STUDY PERIOD.

Year	A	P	CN	Q (in)	Q (acre in)	TSS (lbs.)	TP (lbs.)	TN (lbs.)
2008	185	65.66	74	62.15	11,498	109,432	221	2,866
2009	185	52.02	74	48.55	8,982	85,493	173	2,239
2010	185	56.29	74	52.81	9,769	92,983	188	2,435
2011	185	50.58	74	47.12	8,717	82,968	168	2,173
2012	185	40.56	64	35.34	6,538	26,671	37	1,704
2013	185	44.8	64	39.52	7,312	29,826	41	1,906
2014	185	45.17	64	39.89	7,380	30,102	42	1,923
2015	185	39.73	59	33.48	6,193	25,261	35	1,614
2016	185	40.75	59	34.47	6,378	26,014	36	1,662

Figure 4 illustrates the same tabular data found in Table 7 in a bar graph for each of the main pollutants of concern. While rainfall depths vary between years the overall annual pollutant load to the watershed decreases.

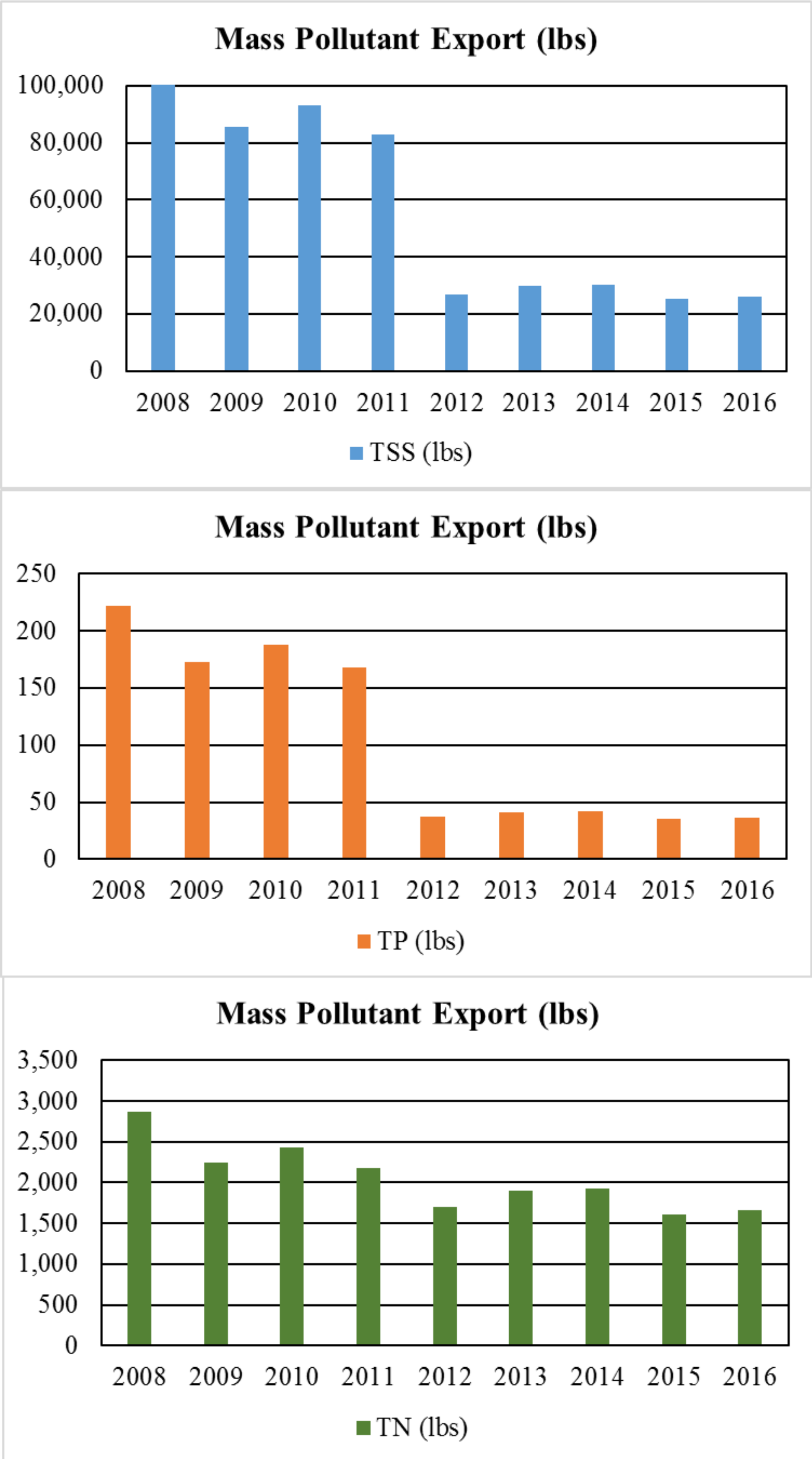

FIGURE 4: GRAPHICAL ANNUAL POLLUTANT EXPORT BASED ON CHANGING LAND USE CONDITIONS

Water Quality

The goal of this objective was to assess the impact of urban watershed stormwater management retrofits that included the implementation of: innovative stormwater controls, wetland restoration, and stream restoration. The output of the research component of this project is the characterization of the water quality and hydrological impacts in the receiving stream during pre-retrofit, mid-project and post-project activities and the dissemination of this information to stakeholders.

As part of this objective, routine monitoring and sampling was conducted in Berry Brook using automated samplers and flow monitoring equipment (QAPP on file at NHDES). The water quality assessment is based on samples collected from twenty-one (21) qualified storm events, at two distinct instream locations. The upstream monitoring location immediately follows the headwaters at the outlet of the Roosevelt Avenue culvert. The downstream monitoring location is near Station Drive, approximately 500 feet prior to discharge to the Cocheco River.

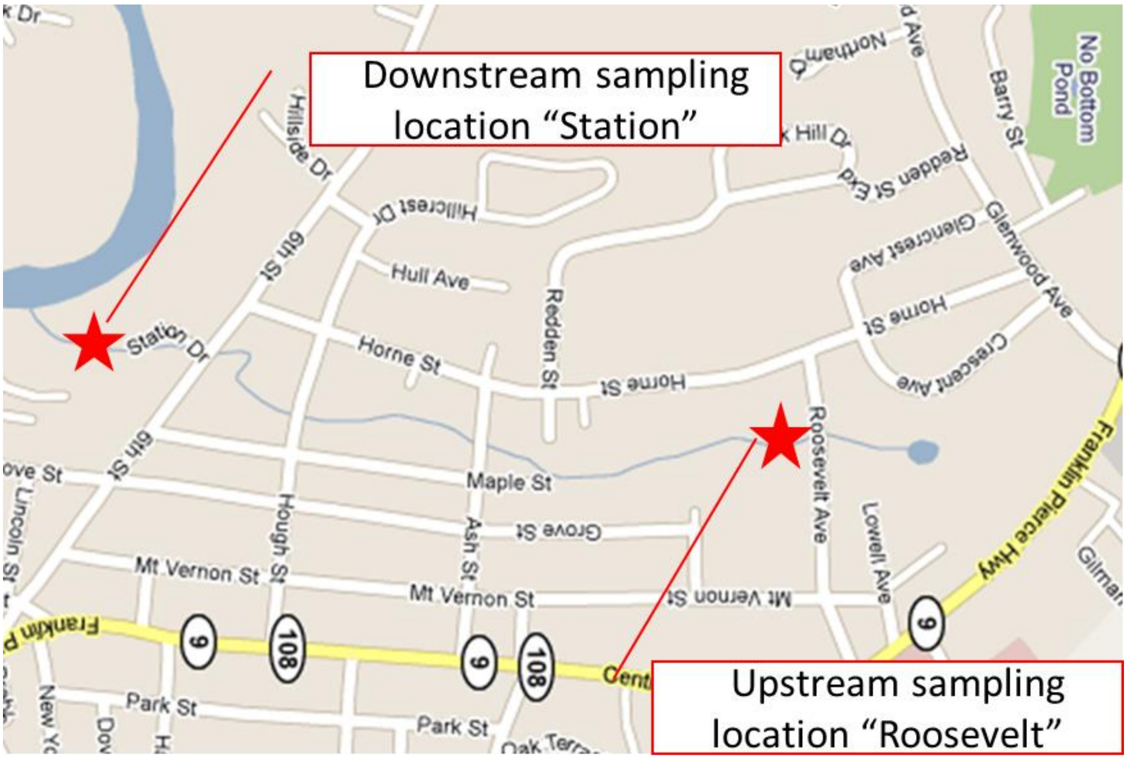

FIGURE 5: MAP SHOWING LOCATION OF SAMPLING STATIONS

Storm event characteristics (Table 8) such as total rainfall depth, peak rainfall intensity, and stream depth recorded at 5-minute intervals provide water quantity data throughout each qualified storm event.

TABLE 8: RAINFALL DATA FROM QUALIFIED STORM EVENTS

Storm Date	Total Rainfall (in)	Peak Intensity (in/hr.)
PRE-RETROFIT		
6/11/2011	1.13	0.24
6/18/2011	0.15	0.15
7/6/2011	0.10	0.04
7/13/2011	0.29	0.24
7/25/2011	0.11	0.04
7/26/2011	0.07	0.06
7/29/2011	0.27	0.09
8/6/2011	0.55	0.15
8/9/2011	0.53	0.20
8/15/2011	1.96	0.27
9/6/2011	0.24	0.06
MINIMUM	**0.07**	**0.04**
MEDIAN	**0.27**	**0.15**
MAXIMUM	**1.96**	**0.27**
MID-PROJECT		
10/19/2012	0.92	0.24
11/8/2012	0.38	0.14
11/13/2012	0.15	0.07
12/2/2012	0.11	0.04
12/7/2012	0.24	0.08
MINIMUM	**0.11**	**0.04**
MEDIAN	**0.24**	**0.08**
MAXIMUM	**0.92**	**0.24**
POST-PROJECT		
10/21/2016	2.73	1.16
10/27/2016	1.87	0.30
4/21/2017	0.76	0.11
5/1/2017	0.75	0.21
5/13/2017	1.66	0.24
MINIMUM	**0.75**	**0.11**
MEDIAN	**1.66**	**0.24**
MAXIMUM	**2.73**	**1.16**

Table 8 lists the rainfall data associated with the 21 qualified storms monitored (11 pre-retrofit, 5 mid-project, and 5 post-project). With the relative small number of monitored storm events over rapidly changing land use characteristics there is naturally some difficulty in determining the effectiveness of LID implementation on overall water quality. The pre-retrofit phase covers a typical distribution of rainfall depths and peak rainfall intensities during spring and summer months. The mid-project phase has a typical distribution of rainfall depths and intensities, but is concentrated in the fall season. The post-project phase covers a distribution of larger rainfall depth and more intense rainfall events and are spread over fall and early spring seasons. The disparity in annual and seasonal rainfall characteristics is common in environmental data, and are difficult to control beyond the selection or targeting of seasonal coverage. As with many stormwater studies the relative low number of qualified events must be considered when evaluating this data set for prediction of long-term trends.

The event mean concentration (EMC) and water quantity data were used to assess stream water quality for individual rainfall events as well as over the course of the three project phases. Water quality parameters included total suspended sediments (TSS), total zinc (TZn), total nitrogen (TN), which includes dissolved inorganic nitrogen (nitrate/nitrite, ammonia) (DIN), and total Kjeldahl nitrogen, and finally total phosphorous (TP). Selection of parameters for routine analysis is based on initial constituent characterization performed over the past six years by UNHSC. Laboratory analysis of water samples were performed by Absolute Resource Associates in Portsmouth, New Hampshire, a certified laboratory for drinking water and waste water.

Table 9 presents median EMC values collected over the course of the project separated by project phase. A flow-weighted composite sampling regimen was utilized for collection of all samples. The analytical results of flow-weighted composite samples provide instream water quality data in the form of event mean concentrations (EMCs).

The median rainfall depth is included as Figure 6.a and 7.a. While pre-retrofit and mid-project phase rainfall depths are similar there is a 144% to 149% difference in median rainfall depth between the pre-retrofit and mid-project phase to the post-project phase, respectively. The larger storm events lend to larger pollutant EMCs are more likely to mobilize instream sediments and sediment associated pollutants, such as phosphorus (Figure 6.b), at the downstream monitoring location (Station) during the post-project phase. The higher TP (Figure 6.c) and TZn (Figure 6.d) EMC values, which are typically sediment bound pollutants, provide additional verification of this assumption.

The disproportionate rainfall depths appear to have less of an effect on instream nitrate concentrations (Figure 6.e), which remain relatively unchanged between monitoring location and across project phases. The slight reduction in nitrate (40% difference) at the upstream location (Roosevelt) between pre- and post- phases may indicate the effectiveness of the denitrifying components of the systems constructed in Berry Brook headwaters. These systems include a subsurface gravel wetland and standard wetland complex, which are the only two systems constructed in this project that target the removal of inorganic nitrogen species. The median TN values (Figure 6.f) show a slight decrease (37%) at the upstream location and a slight increase (-31%) at the downstream location (Station). The increase in TN may be affected by the larger rainfall depths due to the mobilization of organic material and subsequent concentrations of total nitrogen from decaying vegetative matter.

TABLE 9: IN-STREAM WATER QUALITY DATA FOR 5 PARAMETERS AT 2 SAMPLING LOCATIONS ALONG BERRY BROOK PRESENTED IN ORDER FROM HEADWATERS (ROOSEVELT) TO TAILWATER (STATION) FOR EACH PROJECT PHASE. TABULATED VALUES INCLUDE MEDIAN EVENT MEAN CONCENTRATION (EMC) FOR EACH PROJECT PHASE AND PERCENT DIFFERENCE FOR MID- AND POST-PROJECT EMCS COMPARED TO PRE-RETROFIT EMC.

		TSS (mg/l)			Zinc (mg/l)			Nitrate-N (mg/l)			Total Nitrogen (mg/l)			Total Phosphorus (mg/l)		
		Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
Roosevelt	Median EMC	190	40	100	0.02	0.01	0.03	0.3	0.2	0.2	1.8	1.9	1.2	0.36	0.10	0.10
	% Difference		130%	62%		67%	-40%		40%	40%		-8%	37%		112%	112%
Station	Median EMC	45	17	140	0.02	0.01	0.05	0.3	0.3	0.3	1.1	1.2	1.5	0.09	0.02	0.28
	% Difference		93%	-103%		67%	-86%		0%	0%		-4%	-31%		127%	-103%
Average % Difference			112%	-20%		67%	-63%		20%	20%		-6%	3%		120%	5%

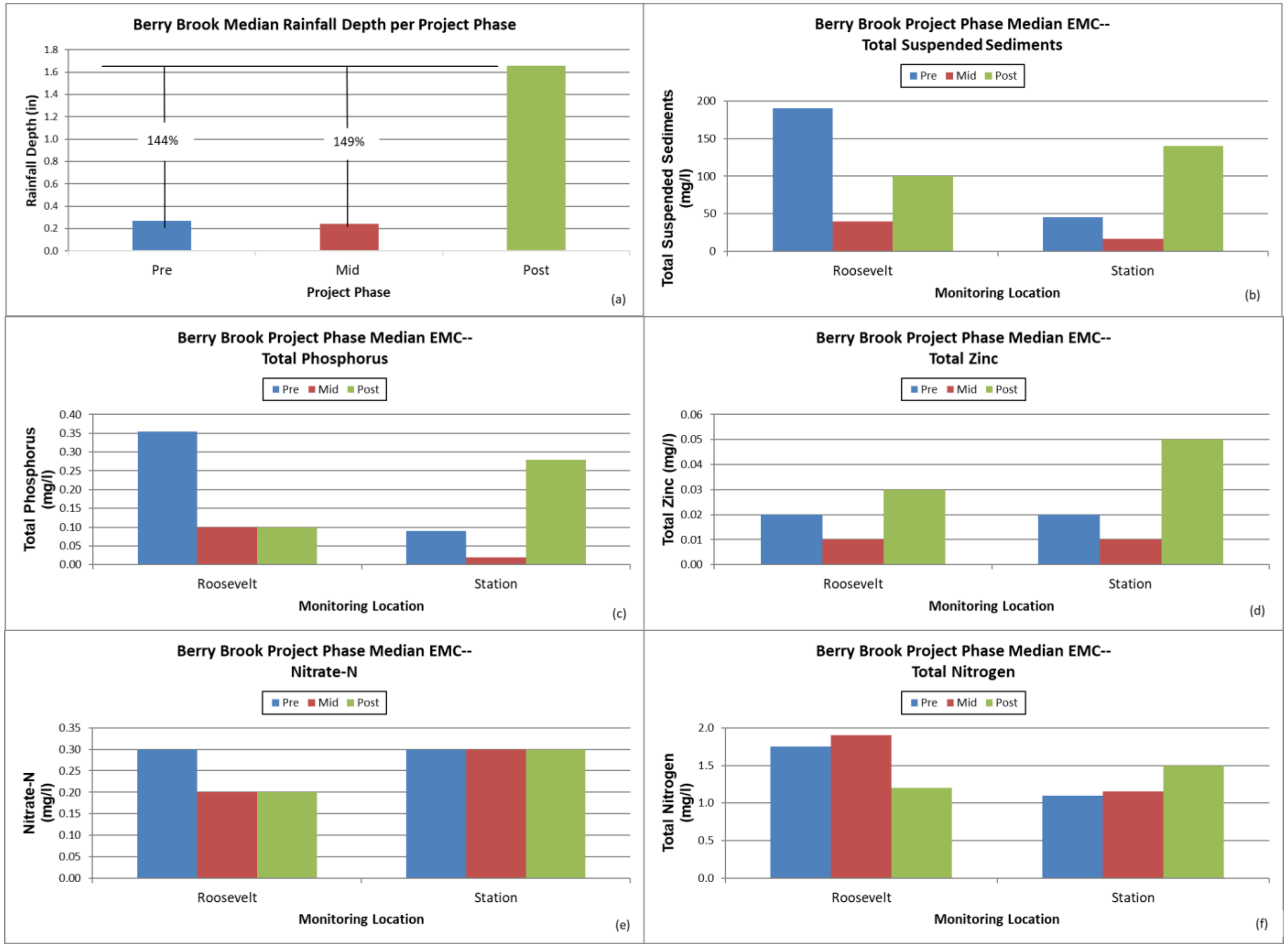

FIGURE 6: SIMPLE BAR CHART OF MEDIAN EVENT MEAN CONCENTRATIONS (EMC) AT THE TWO MONITORING LOCATIONS UPSTREAM (ROOSEVELT) AND DOWNSTREAM (STATION) DURING EACH PHASE OF THE PROJECT.

Due to the fact that rainfall depth is an uncontrolled variable that drives water chemistry and subsequent pollutant concentrations rainfall depth weighed EMCs were calculated. In order to provide an equivalent assessment across each project phase the median EMC values were divided by the median rainfall depths producing a weighted EMC per inch of rainfall depth. This data is presented in Table 9 and Figure 6 and is separated by project phase. By weighting the EMCs the data can more accurately be compared in consideration of both the water quality and water quantity values. This provides a more accurate representation of pollutant concentrations monitored during each project phase. The weighted EMC values for TSS (Figure 7.b), TP (Figure 7.c), and TZn (Figure 7.d) show a decrease in these parameters though each project phase.

The weighted EMC values show a significant reduction in nitrate and TN (>80%) between the pre- and post-project phases. Reductions in all parameters at both monitoring locations over the course of the project indicate that LID implementation, daylighting of the brook, and construction of a wetlands complex were effective at mitigating pollutants from the directly connected impervious cover.

TABLE 10: WEIGHTED IN-STREAM WATER QUALITY DATA WHICH DIVIDES THE MEDIAN EVENT MEAN CONCENTRATION (EMC) BY THE MEDIAN RAINFALL DEPTH PER PROJECT PHASE. THIS CALCULATION RESULTS IN PARAMETER CONCENTRATION PER INCH OF RAINFALL.

		TSS (mg/l) / (in)			Zinc (mg/l) / (in)			Nitrate-N (mg/l) / (in)			Total Nitrogen (mg/l) / (in)			Total Phosphorus (mg/l) / (in)		
		Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post	Pre	Mid	Post
Roosevelt	Weighted EMC	704	167	60	0.07	0.04	0.02	1.1	0.8	0.1	6.5	7.9	0.7	1.31	0.42	0.06
	% Difference		123%	168%		56%	121%		29%	161%		-20%	160%		104%	182%
Station	Weighted EMC	167	69	85	0.07	0.04	0.03	1.1	1.3	0.2	4.1	4.8	0.9	0.33	0.08	0.17
	% Difference		83%	65%		56%	84%		-12%	144%		-16%	127%		120%	65%
Average	**% Difference**		103%	117%		56%	103%		8%	152%		-18%	144%		112%	124%

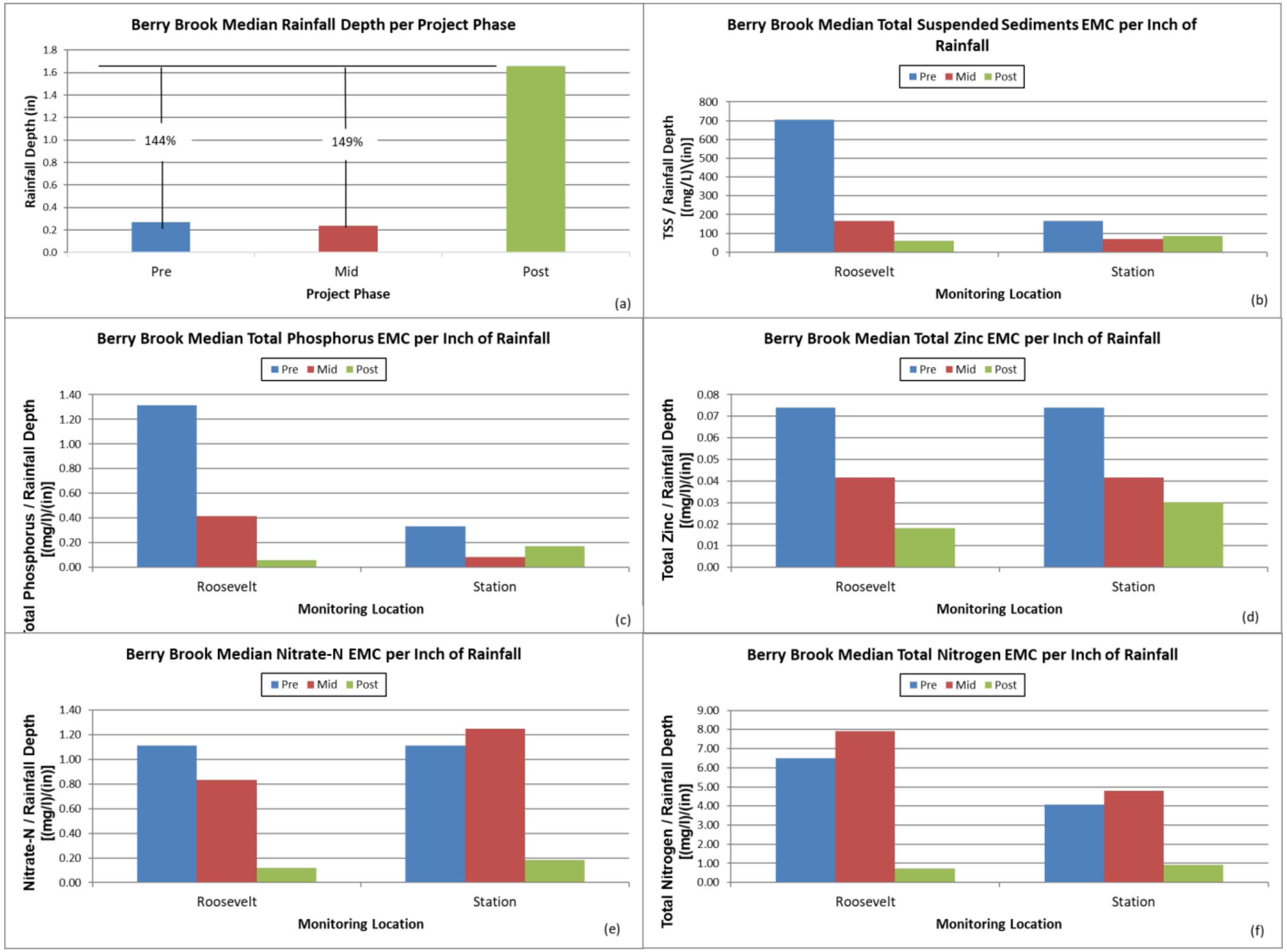

FIGURE 7: SIMPLE BAR CHARTS OF THE WEIGHTED EVENT MEAN CONCENTRATIONS (EMC) AT THE TWO MONITORING LOCATIONS, UPSTREAM (ROOSEVELT) AND DOWNSTREAM (STATION), DURING EACH PHASE OF THE PROJECT.

Interquartile distributions are presented as box and whisker plots (Figure 8 and rainfall weighted box and whisker plots (Figure 9) for the range of pollutants for each project phase. Analysis of quartile distributions helps characterize trends in terms of range, maximum, minimum, and median characteristics of the dataset. In all cases interquartile ranges trend downward toward irreducible concentrations indicating that disconnection and treatment strategies are working. These results suggest that for most pollutants monitored (TSS, TZn, and TP) LID retrofits are moving levels down toward background.

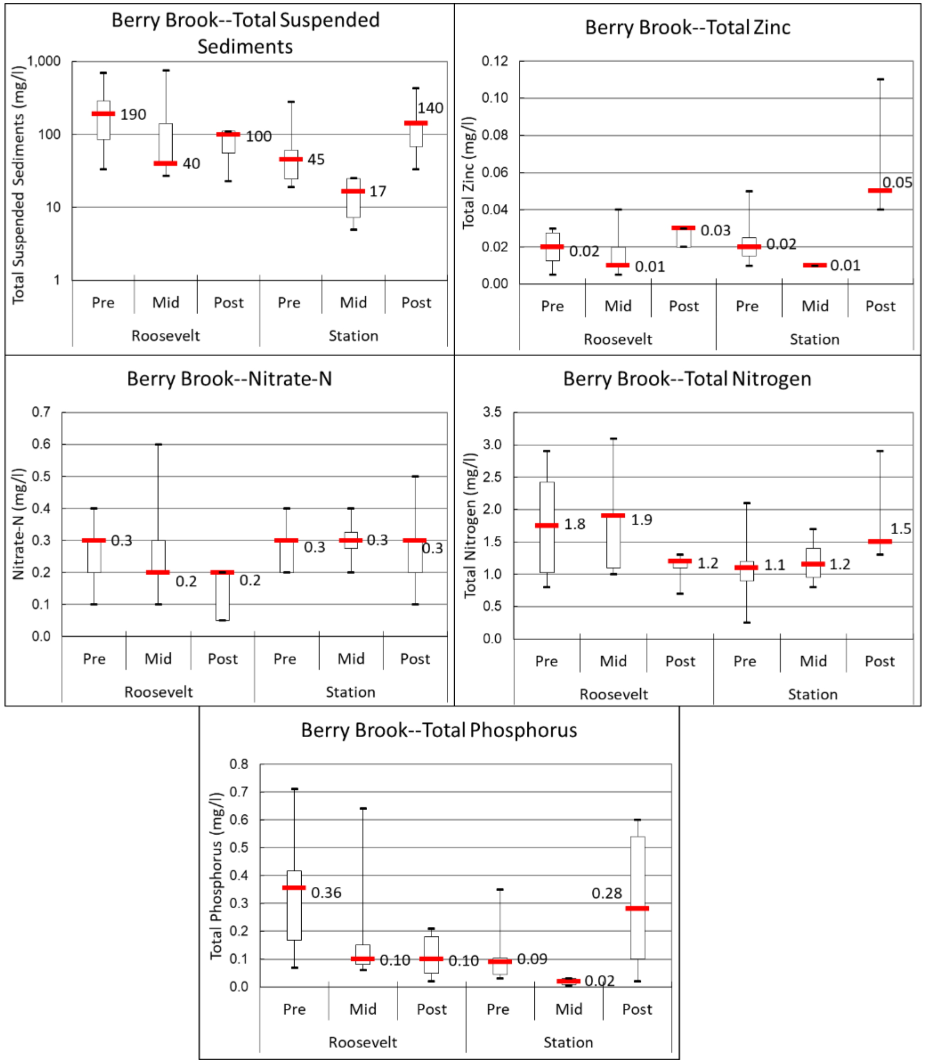

FIGURE 8: BOX AND WHISKER PLOTS FOR THE RANGE OF EMC VALUES AT SAMPLING LOCATIONS ACROSS PROJECT PHASES.

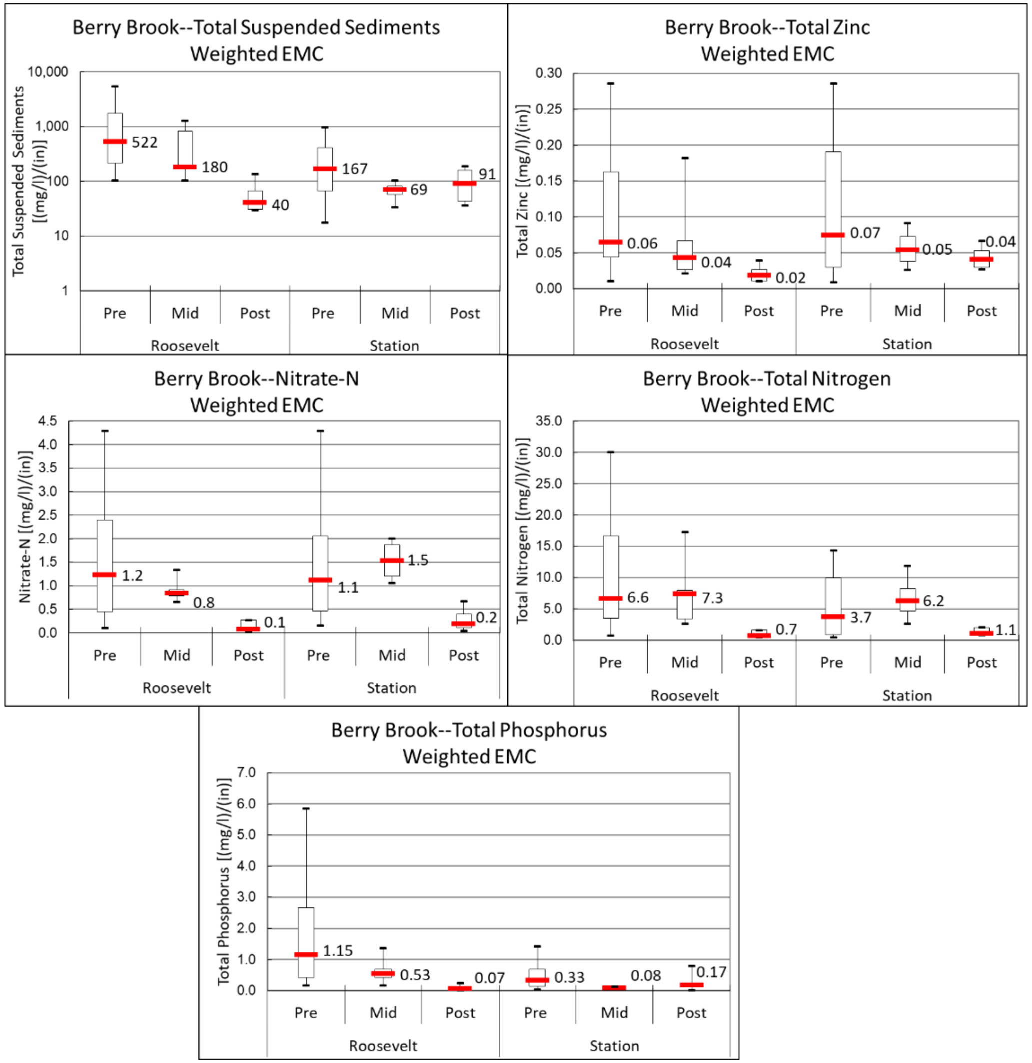

FIGURE 9: BOX AND WHISKER PLOTS FOR THE RANGE OF WEIGHTED EMC VALUES AT SAMPLING LOCATIONS ACROSS PROJECT PHASES.

Temperature

As urbanization and build-out occurs, the thermal regime of the surrounding environment is altered. In the summers, heated stormwater runoff flows into receiving waters where it mixes, and potentially increases the base temperature of the surface water in lakes, streams, and estuaries. The amount of heat transferred, and the degree of thermal pollution is of great importance for fisheries management and the ecological integrity of receiving waters. Coldwater fisheries in particular are most sensitive to thermal pollution.

The increase in summer thermal energy in stormwater runoff is primarily a product of the increase in IC of the surrounding area. IC absorbs and emits heat, creating air and surface temperatures that are significantly higher than those of natural, vegetated areas. An increase in IC also results in additional surface runoff. The combination of these two phenomena creates a larger volume of runoff with increased temperatures. Alternatively reductions in IC or reductions in EIC through stormwater controls should shift temperature regimes in receiving waters toward cooler temperatures or fewer degree days during the summer months. Rather than using some form of EMC to describe temperature and temperature impacts, a degree day method was developed to assess project impacts on Berry Brook summer water temperatures. In this context one degree day is a day when the average stream temperature is one degree Fahrenheit above 65 degrees F. This is important as the temperature that a Brook Trout begins to feel heat stress is 65 °F. Therefore a day with an average daily stream temperature of 71 degrees would represent 6 degree days. Over each summer season, the degree days may be totaled as an indicator of overall heat stress to cold water systems. Results throughout the project period are presented in Figure 10. Results from Roosevelt (upstream) and Station (downstream) monitoring stations show a dramatic decrease in degree days between pre-project and both mid and post-project data sets. These results reinforce the hydrological data set in demonstrating that disconnection of IC through GI and LID infrastructure is reestablishing pre-development hydrology, decreasing impacts of warmer surface runoff, and increasing cooler base flow from shallow groundwater.

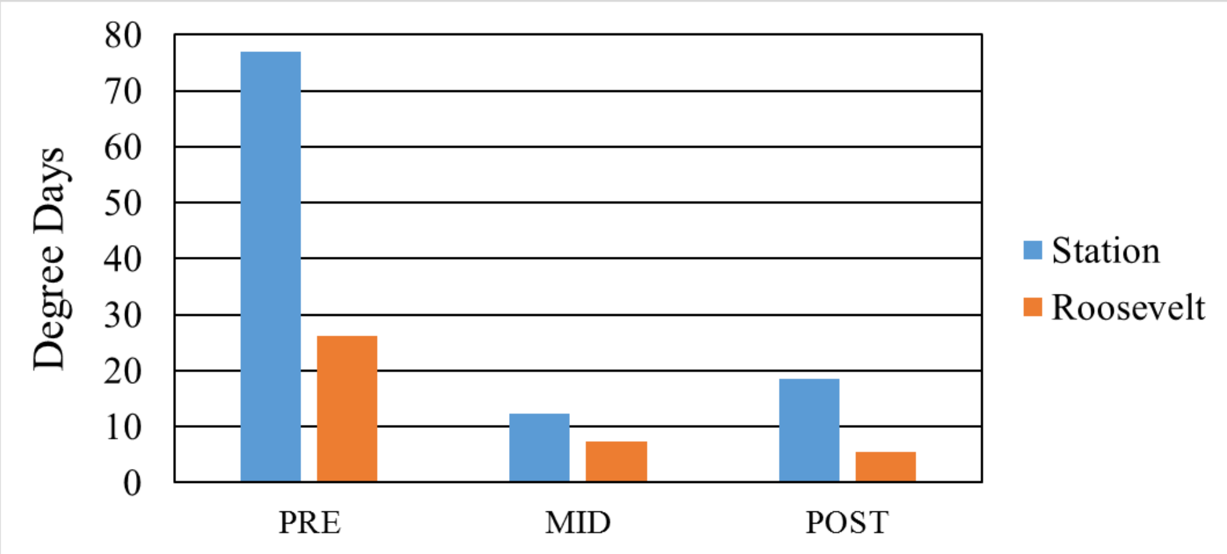

FIGURE 10: SUMMER PERIOD CUMULATIVE DEGREE DAYS OVER 65°F THRESHOLD THROUGHOUT THE PROJECT PERIOD.

Objective 5: Operation and Maintenance

Operation and maintenance guidelines and checklists for all classes of BMPs implemented throughout the project period have been developed and provided to City staff.

Deliverable 12: The O&M documentation is on file with the City and is provided in appendix B.

Objective 7 (6): Provide Grant and Project management

Deliverable 13: All interim progress reports are on file with NHDES.

CONCLUSIONS AND RECOMMENDATIONS

The implementation efforts resulting from this project have demonstrated the effectiveness of green infrastructure implementation (reduction of EIC) towards watershed improvements with respect to hydrologic, water quality at the watershed scale. The modeling, stream gauging and water quality sampling results indicate that storm event hydrology and water quality parameters have improved in Berry Brook as a result of the watershed improvement efforts associated with this project. Beyond the implementation and modeling initiatives, this study examined the manner in which urban watershed issues might be addressed in a holistic approach: clearly delineating water quality problems, working closely with a community, having the community involved with decisions/outreach such that they "own" the solution, and implementing strategies at the local scale in the context of the watershed. While this was not a required task in the project the outcomes weigh heavily on the future NPS management decisions in the city and region. While it's difficult to measure and quantify what municipal ownership and investment in NPS management decisions look like this project not only led to the reduction of EIC to the 10% target, but changed the way stormwater BMPs where designed and how sites were selected. Outputs include at least three new types of stormwater controls that are more maintainable and ultimately more cost effective for the community. This re-invention and ownership process is one of the most unique and impactful developments of this project, and has sustained implementation efforts as a matter of routine within the community beyond the term and scope of the project.

Currently much of the environmental investigation in New Hampshire and other states has gone into identifying impairment locations, pollutant stressors, and their respective sources. This information is important as we begin to understand the environmental restoration challenges that lie ahead. Water resources and in particular, NPS pollution and stormwater management, is an area that is targeted for significant investments in the years to come. To move forward on this objective there needs to be a clear strategy that addresses the financial and municipal ownership aspects as well as optimized restoration approaches. Systems need to be well designed and effective, but they also need to be amenable to the long-term municipal owners. Often there is disproportionate focus on the technical elements and the loading models and not enough effort on the long-term operation and maintenance of the systems.

Many studies have identified the effectiveness and costs of green infrastructure and low impact development at the system and site/development scale. The Berry Brook Project has truly been a unique study that has taken cost/benefit to the watershed and municipal scale. By implementing systems that are co-developed with municipal partners long-term operation and implementation efforts are less of an uncertainty. The findings from this study do not answer all of the questions behind urban restoration, but certainly add to our understanding of watershed and ecosystem response as a result of LID implementation. The synthesis between the reduction of effective impervious cover and hydrologic and water quality response will aid future watershed planners and engineers in optimizing our efforts and understanding benefits. The innovations developed from the implementation efforts are illustrative of the fact that planning efforts and optimization of system sizing and configuration need to be flexible so as to accommodate and capitalize on the dynamic nature of the process of adoption and installation. Flexibility and innovation are not common words in traditional watershed management plans where solutions are predetermined and siting within the watershed already optimized. It is an interesting aside that while all those traditional planning efforts were completed numerous times throughout this project few, if any, installations actually were installed where and as originally designed. The reasons for this are varied and plentiful. Some are predictable such as constraints around property ownership, rights of ways, and difficulties with acquiring maintenance easements. Others are confounding and difficult to plan for such as the existence of relic structures, utilities that were not mapped or known, contaminated sediments and uncovering historic artifacts that need documentation and proper permitting.

Municipal public works staff in coastal NH are faced with an assortment of threats from unmanaged developed areas, aging municipal infrastructure and changing precipitation patterns. This project explored the processes that bridge the technical performance gap that exists between innovative technology development and its implementation in a municipal context. The integration of research findings and evidence into practice is a field known as implementation science. This field has grown over the past decade (Hart and Bell, 2013), and is particularly robust in the area of sustainability science (Clark, 2010). As evidenced by the outcomes of this project, municipal implementation experience is critical to adapt “text book” research-based designs with what is practical for a public works department working in an urban setting. Future challenges with respect to NPS pollution are challenging and do not appear to diminish in the near or distant future. In order to face those challenges the deliverables from the Berry Brook project should help both regulators and municipalities adapt their mitigation and restoration efforts toward opportunistic implementation and resiliency planning. There appears to be too much focus on individual projects and getting the maximum pollutant reductions for the minimum effort. While important, this project emphasized that implementation is more of a cultural shift replacing conventional rain and drain strategies with modern day approaches that GI offers. Once this institutional shift occurred and was accepted by the leadership structural innovations occurred making the GI technologies easier to implement and more consistent with the organizational culture. There is no end to municipal work and improvements to infrastructure, once the shift is made future upgrades can be more easily adapted to achieve resiliency benefits.

Resilience is defined as the capacity of an ecosystem to absorb repeated disturbances or shocks and adapt to change without continually degrading and fundamentally switching to an alternative stable state (Holling, 1973). Precipitation patterns are changing. Overall, our region is experiencing changing precipitation and more extreme storm events. Between 1996 and 2014, extreme precipitation (two inches or more in one day) in the Northeast was 53% higher than it was in the previous 94 years (PREP, 2018) The 2006 Mother's Day Storm alone greatly increased levels of dissolved organic matter and brought salinity levels close to zero for five days. Annual precipitation is expected to increase by as much as 20 percent by the end of the 21st century compared to the late 20th century, and extreme precipitation events are projected to increase in frequency and in the amount of precipitation produced (CRHC, 2016). Despite these troubling patterns the spread of impervious cover continues to threaten coastal communities like Dover. Between 1990 and 2010, impervious surfaces in our watershed increased by 120% (UNHSC, 2015) and have continued to increase over the last five years. The city of Dover had the largest increase in IC between 2010-2015 with an addition of 56 acres of IC or 11.2 acres per year (PREP, 2018). These changes are indeed threats to our water quality and standard of living and the results achieved through these efforts demonstrate the potential to build resilience in the landscape to these stressors increasing and fortifying community resiliency.

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APPENDICES